Energy security and the transport sector

Sujith Kollamthodi (AEA)
Heather Haydock (AEA)
Angela Falconer (AEA)

4 June 2010


Contact details

Ian Skinner
AEA
Central House
14 Upper Woburn Place
London UK
WC1H 0JN
T +44 (0)870 190 2817
E EUTransportGHG2050@aeat.co.uk

Ian Hodgson
Clean Air and Transport Unit
Environment Directorate General
European Commission
ENV.C.3 Brussels
Belgium
T +32 (0)2 298 6431
E Ian.Hodgson@ec.europa.eu

Project
www.eutransportghg2050.eu

Partners
www.aeat.co.uk
www.cedelft.nl
www.tno.nl
www.isis-it.com
www.milieu.be
Table of contents

Executive Summary iv

1 Introduction 1
   1.1 Topic of this paper 1
   1.2 Background to project and its objectives 1
   1.3 Background and purpose of the paper 5
   1.4 Structure of the paper 5

2 Overview of energy security in relation to the transport sector 6
   2.1 What do we mean by energy security? 6
   2.2 What does this mean for transport? 6
   2.3 To what extent is the current transport energy supply “not secure”? 7
   2.4 What factors contribute to improving energy security? 10

3 The extent of energy security in the transport sector 13
   3.1 Existing and projected demand for transport fuels 13
   3.2 Existing and projected supply of raw materials for transport fuel production 15
   3.3 Are our transport energy supplies likely to become more or less secure? 19

4 Existing approaches to quantifying energy security benefits of GHG abatement options 21
   4.1 Introduction 21
   4.2 IEA approach to quantifying energy security impacts 21
   4.3 Ecofys study for the European Commission 22
   4.4 World Resources Institute approach 25
   4.5 ECN approach 26
   4.1 Summary 27

5 Proposed approach for quantifying the energy security impacts of GHG abatement options for the transport sector 28
   5.1 Introduction 28
   5.2 The proposed approach 28
   5.3 Demonstration of the approach for light duty road vehicles 30
   5.4 Interpretation 34
   5.5 Further development of the approach 34

6 Summary and conclusions 36

References 38
Executive Summary

Overview

Energy consumption for transport is dominated today by the demand for oil to produce petrol, diesel, gas oil, marine fuels, and kerosene for road, rail, marine and air transport. There is also a small but growing demand for biofuels, natural gas plays a minor role as a transport fuel, and electricity is used for rail transport. In 2006, oil accounted for over 96% of final energy consumption for transport in the EU. This makes transport, and hence the wider economy of Europe, very dependent on the availability of oil and petroleum products. Therefore, energy security for the transport sector is often equated with oil security. However, in the future, it is likely that the use of alternative fuels and energy carriers will become more widespread in the transport sector as means of reducing the climate change impacts of transport. Additionally, it is possible that a range of demand reduction measures could be implemented to reduce GHG emissions from the transport sector. The implementation of options for reducing transport sector GHG emissions may also have impacts on energy security, and hence there is a need to understand, and where possible, quantify the impacts of such measures on energy security.

To what extent is the current transport energy supply “not secure”? 

The extent to which the current energy supply for the transport sector is “not secure” can be analysed by examining the three key dimensions of sufficiency, affordability, and sustainability. Based on current figures, Europe imports much more oil than it produces and imports are rising year-on-year. However, this import dependency has not (so far) led to physical unavailability – sufficient oil is available on the international market, although there have been localised incidents where there have been short term disruptions. Growing demand in non-OECD countries coupled with political instability in some oil-producing countries may lead to supply problems in the future. Affordability is a key aspect of energy security, and the Organisation of Petroleum Exporting Countries (OPEC) has a strong influence on oil prices. This concentration of supply within a trading structure is sometimes referred to as “market power”, and this is an important concept when discussing energy security issues.

Factors that contribute to improving energy security

There are five main ways of improving energy security:

Making greater use of indigenous supplies of energy

Indigenous supplies of oil are limited and declining in Europe. There is some limited scope to recover more oil via the use of advanced technologies, but it is unlikely that there will be major new discoveries of oil in Europe in the future. Significant increases in indigenous supply can therefore only be achieved by moving to alternative fuels or energy carriers.

Increasing diversity of supply

Diversity of supply encompasses diversity of fuels used for transport, diversity of suppliers of those fuels and diversity of supply routes. Alternative fuels such as electricity, natural gas, biofuels, hydrogen and coal-to-liquid (CTL) fuels can reduce reliance on oil supplies, although it is likely that a majority of vehicles will be petrol or diesel fuelled for many years to come.

Establishing long-term supply arrangements

Long-term supply arrangements are a favoured option to ensure security of natural gas supply; however such arrangements are less relevant for oil, which is traded on the international markets and imported to Europe by ship as well as by pipeline.
Increasing strategic reserves
Since 1968, EU Member States have been required to keep a minimum of 90 days’ supply of petroleum as a Strategic Petroleum Reserve (SPR). This SPR must be kept within the EU but not necessarily within the Member State. These reserves are intended to provide a buffer against short-term cuts in supply to the country and may also be used in the event of a fault or industrial action at a refinery.

Reducing demand
Simply reducing the demand for transport fuels will improve energy security – the less oil to be imported the lower the vulnerability to supply constraints or increased oil prices. This can be achieved by improving the efficiency by which fuel is used to provide transport, by encouraging modal shift, improving vehicle efficiencies, introducing measures such as driver training or lower speed limits, and optimising freight logistics.

Quantifying the energy security benefits of GHG abatement options for the transport sector
Whilst research has already been carried out to analyse the GHG benefits associated with different emissions abatement options for the transport sector, the effects that such options are likely to have on energy security have not been fully quantified to date. Initial work in this area has been carried out by the International Energy Agency (IEA), but this analysis does not allow for all aspects of energy security to be taken into account. Further work has been commissioned by the European Commission in this area, but again, the findings from this analysis do not take into account all aspects of energy security.

Existing approaches to quantifying energy security benefits
In 2009, the European Commission DG Environment commissioned a study from the consultancy Ecofys entitled “Analysis of Impacts of Climate Change Policies on Energy Security”, and as part of this research, a comprehensive review of existing indicators for quantifying energy security was carried out. Drawing from this recent review, it is clear that there are two types of indicator that can be used for quantifying energy security impacts/benefits, as follows:

- Vulnerability-based indicators
- Outcome-based indicators

As set out in the Ecofys paper, vulnerability-based indicators can be used to quantify the “potential risk and/or magnitude of energy security impact should it actually occur”, whilst outcome-based indicators “aim to measure the actual outcome of energy security”, in terms of real-world impacts. Ecofys found that the majority of energy security indicators are vulnerability-based indicators. The key findings from this study were as follows:

- The vast majority of energy security indicators focus on quantifying vulnerability rather than outcomes;
- Outcome-based indicators tend to make use of detailed, situation-specific modelling, and as such are more limited in how widely they can be applied. Vulnerability-based indicators can be more widely used.
- None of the current energy security indicators are able to provide a suitable measure of all the causes of energy security, and attempts to do this reduce the transparency of the indicator.
- For a number of the indicators, the linkage between the indicator and energy security is not clear. Examples include net import dependence, which has been proposed as a proxy indicator for physical unavailability impacts, and the general business environment, which has been proposed as a proxy for investment in energy infrastructure.

The Ecofys study concluded that whilst ideally it would be preferable to develop outcome-based indicators that can be used to assess the actual impacts of energy security on the real world, such an approach would be too complex. With this in mind, Ecofys proceeded to develop a
vulnerability-based approach for assessing energy security that draws on previous work carried out by the IEA that led to the development of their energy security indices for price and volume (ESI\text{price} and ESI\text{volume}).

Whilst the approach developed by Ecofys is potentially useful in being able to quantify energy security impacts, it is clear that there are a number of areas where the Ecofys approach is not adequate for assessing transport sector abatement options. It would appear that biofuels have been excluded from Ecofys’ analysis of resource concentration/market power. Essentially, the argument put forward is that because biofuels will not make up a significant share of transport energy demand by 2020, the energy security impacts will be minimal. Where the IEA has previously looked at the impacts of biofuels, it has done so purely from the perspective of the impacts of biofuels uptake on fossil fuel use and the ESI\text{price} indicator. Given that the scope of this new study looks beyond 2020 and towards 2050, there are obviously some limitations associated with the Ecofys and IEA approaches, as there is the possibility for biofuels to play a significant role in reducing transport sector GHG emissions. Additionally, the IEA looked at just one biofuel feedstock chain (wheat-derived ethanol), but there are clearly many alternative chains that would need to be analysed.

**Proposed framework for quantifying the energy security impacts of climate policies in the transport sector**

Moving beyond the Ecofys study, there is a need for a more comprehensive approach that can take into account the full range of parameters that play a role in determining energy security in the transport sector. In particular, it is proposed that such an approach should include the following parameters:

- linkage between price of new energy source and oil price
- proportion of vehicle fleet able to use new energy source
- cost of new energy source compared to oil
- surplus of supply capacity over demand
- susceptibility of new energy source to disruptions (extreme events and inadequate market structures)
- resource concentration for the supply of the new energy source

In order to be able to develop a full quantitative approach for assessing the energy security impacts of possible GHG reduction policies for the transport sector, it would be necessary to have access to quantitative data for all of the above parameters for each potential new energy source. Only in this way could all the energy security impacts/benefits be fully evaluated. It was not possible within the scope of this project to carry detailed analysis to identify quantitative data for each of the key assessment parameters. Indeed, for many of the parameters, it may not be possible to readily identify quantitative datasets, and at this point in time, data are not available for all alternative energy sources to cover the full 2010-2050 timeframe.

Nonetheless, an initial framework has been developed using the above-listed parameters as the basis for assessing energy security impacts and benefits. The framework is applied using a semi-quantitative approach (multi-criteria analysis) to quantify the energy security benefits of transport options. Using this approach, it is possible to calculate initial numerical energy security ratings for each abatement option. The higher the percentage rating, the better the performance of the option with respect to energy security. The results of the analysis are presented overleaf in Table ES.1. It should be stressed that the assessment presented below is based on the current situation with respect to fuel costs, vehicle capabilities, and the current methods used to produce the fuels included in this analysis.
Table ES.0.1 Results of the multi-criteria analysis

<table>
<thead>
<tr>
<th>Transport Policy Option</th>
<th>Total MCA score (maximum 600)</th>
<th>MCA score as a percentage</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy demand reduction</td>
<td>450</td>
<td>75%</td>
<td>1</td>
</tr>
<tr>
<td>Electricity</td>
<td>400</td>
<td>67%</td>
<td>2</td>
</tr>
<tr>
<td>Biofuel blends and fungible types</td>
<td>350</td>
<td>58%</td>
<td>3</td>
</tr>
<tr>
<td>Gasoline/diesel</td>
<td>300</td>
<td>50%</td>
<td>4</td>
</tr>
<tr>
<td>Pure non-fungible biofuel</td>
<td>250</td>
<td>42%</td>
<td>5</td>
</tr>
<tr>
<td>LPG</td>
<td>213</td>
<td>35%</td>
<td>6</td>
</tr>
<tr>
<td>Natural gas</td>
<td>163</td>
<td>27%</td>
<td>7</td>
</tr>
<tr>
<td>Hydrogen (produced from natural gas)</td>
<td>163</td>
<td>27%</td>
<td>7</td>
</tr>
</tbody>
</table>

The analysis clearly shows that the optimal energy security benefit is obtained by approaches that eliminate need for a certain amount of energy. Electricity and biofuel blends are identified as the next best options for energy security in the transport sector due to their low resource concentration and, for electricity, a low correlation with crude oil prices. The proportion of vehicles able to use electricity is however very low but high for blended biofuels.

Natural gas and hydrogen produced using natural gas score low in the assessment due to high resource concentration and susceptibility to extreme events. However, it must be noted that the results and rank ordering would look very different if the analysis were to be carried out for future years.

Further development of the approach

The research carried out in this study has developed a framework that can be used for quantitatively assessing the energy security impacts/benefits of different transport sector GHG abatement options. However, due to a lack of data on selected parameters and for some abatement options, it has not been possible to develop a fully quantitative assessment methodology. Beyond this project, it is recommended that the assessment methodology could be further developed to incorporate a more complete approach to quantifying the energy security impacts of transport sector abatement options. In particular, it would be useful to carry out detailed research to identify quantitative datasets for the various assessment criteria used to characterise each of the abatement options. In some cases, approaches developed for other studies could be used to identify the relevant quantitative datasets. For example, the previous research carried out by IEA and Ecofys has been used to develop an approach for quantifying resource concentration using the ESI\_price and ESI\_volume indicators. Alternatively, the Energy Security Market Concentration (ESMC) indicator, which is based on the Herfindahl-Hirschman Index\(^1\) could be used in this framework as an objective measure of resource concentration. However, a significant amount of detailed quantitative analysis would be required in order to develop such values for all relevant transport-sector abatement options, as previous research has not examined some of the key abatement options (e.g. biofuels) in detail. Similarly, for other assessment criteria, more detailed research is required to be able to assign full quantitative values to these parameters, although it should be noted that objective data are likely to be already available for some of the assessment criteria (e.g. fuel costs and the ability of the vehicle fleet to use particular fuels).

For some fuel-switching abatement options, there are a variety of methods by which the replacement fuel can be produced, each of which could have very different energy security implications. For example, biofuels can be produced from a variety of different resource feedstocks, whilst hydrogen can be produced from natural gas, fossil-based electricity, or renewable electricity, amongst other production mechanisms. Similarly, electricity can be produced from a number of different energy sources, each of which will have different levels of

---

\(^1\) The Herfindahl-Hirschman Index is equal to the sum of the square of the individual market shares of all the participants in a particular market.
resource concentration, and consequently, different energy security impacts. Comprehensive analysis of each of these different options would be required in order to fully understand the energy security impacts of transport sector abatement options, particularly given the need to look out to 2050.

In addition to developing robust, quantitative datasets for each of the assessment criteria, it may also be useful to be able to weight each of the assessment criteria to reflect their respective levels of importance. The development of suitable weighting factors would require discussions with Commission officials and possibly further consultation with industry and NGO stakeholders, in order to ensure that appropriate factors for each of the criteria are developed.
1 Introduction

1.1 Topic of this paper

This paper presents a methodology developed under the EU Transport GHG: Routes to 2050 project to quantify the energy security impacts of climate change abatement options in the transport sector. The approach makes use of multi-criteria analysis and is demonstrated using semi-quantitative scoring. Further work would be required to apply this methodology comprehensively and using actual data.

The paper also includes background information introducing on energy security and how energy security issues affect the transport sector in Europe. It describes the means by which the energy security in the transport sector can be improved, and reviews a selection of methods that have been developed in the past for analysing energy security impacts when assessing the impacts of climate change abatement options in the transport sector.

1.2 The contribution of transport to GHG emissions

The EU-27’s greenhouse gas (GHG) emissions from transport have been increasing and are projected to continue to do so. The rate of growth of transport’s GHG emissions has the potential to undermine the EU’s efforts to meet potential, long-term GHG emission reduction targets if no action is taken to reduce these emissions. This is illustrated in Figure 1 (provided by the EEA), which shows the potential reductions that would be required by the EU if economy-wide emissions reductions targets for 2050 of either 60% or 80% (compared to 1990 levels) were agreed and if GHG emissions from transport continued to increase at their recent rate of growth. The figure is simplistic in that it assumes linear reductions and increases. However it shows that unless action is taken, by 2050 transport GHG emissions alone would exceed an 80% reduction target for all sectors or make up the vast majority of a 60% reduction target. This illustrates the scale of the challenge facing the transport sector given that it is unlikely that GHG emissions from other sectors will be eliminated entirely.

Figure 1: EU overall emissions trajectories against transport emissions (indexed)

![EU overall emissions trajectories against transport emissions (indexed)](image)

Source: EC DG Energy (2010) and SULTAN Illustrative Scenarios Tool

The extent of the recent growth in transport emissions is reinforced by Figure 2, which presents a sectoral split of trends in CO₂ emissions over recent years. Whilst the CO₂ emissions from other sectors have levelled out or have begun to decrease, transport’s CO₂ emissions have risen steadily since 1990. It should be noted that whilst Figure 2 is presented in terms of CO₂ emissions, very similar trends are evident for GHG emissions (in terms of CO₂ equivalent) since CO₂ emissions represent 98% of transport’s GHG emissions.

Figure 2: Carbon dioxide emissions by sector EU-27 (indexed)³

The vast majority of European transport’s GHG emissions are produced by road transport, as illustrated in Figure 3, while international shipping and international aviation are other significant contributors.

Recent trends in CO₂ emissions from transport are also expected to continue, as can be seen from Table 2 below. Between 2000 and 2050, the JRC (2008) estimates that GHG emissions from domestic transport in the EU-27 will increase by 24%, during which time emissions from road transport are projected to increase by 19% and those from domestic aviation by 45%. It is important to note that these projections do not include emissions from international aviation and maritime transport, which are also expected to increase due to the growth in world trade and tourism.

Figure 3: Share by Mode in Total Transport Greenhouse Gas Emissions (GHG), including International Bunkers: EU-27 (2007)

Note: The figures include international bunker fuels for aviation and navigation (domestic and international)
*** Railways data excludes indirect emissions from electricity consumption

Table 2: CO₂ emissions projection for 2050 by end-users in the EU-27, in Millions tonnes of Carbon

<table>
<thead>
<tr>
<th>End user Category</th>
<th>1990</th>
<th>2000</th>
<th>2010</th>
<th>2020</th>
<th>2030</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road transport</td>
<td>695</td>
<td>825</td>
<td>905</td>
<td>980</td>
<td>1002</td>
<td>1018</td>
</tr>
<tr>
<td>Rail</td>
<td>29</td>
<td>29</td>
<td>27</td>
<td>27</td>
<td>21</td>
<td>20</td>
</tr>
<tr>
<td>Domestic Aviation</td>
<td>86</td>
<td>134</td>
<td>179</td>
<td>206</td>
<td>237</td>
<td>244</td>
</tr>
<tr>
<td>Inland navigation</td>
<td>21</td>
<td>16</td>
<td>16</td>
<td>17</td>
<td>17</td>
<td>17</td>
</tr>
<tr>
<td>Total</td>
<td>810</td>
<td>988</td>
<td>1110</td>
<td>1213</td>
<td>1260</td>
<td>1299</td>
</tr>
</tbody>
</table>

Figures from the EEA (2009), illustrate the recent growth in GHG emissions from international aviation, as they estimate that these increased in the EU by 90% (60 Mt CO₂e) between 1990 and 2005; international aviation emissions will thus become an ever more significant contributor to transport’s GHG emissions if current trends continue. Furthermore, the IPCC has estimated that the total impact of aviation on climate change is currently at least twice as high as that from CO₂ emissions alone, notably due to aircrafts’ emissions of nitrogen oxides (NOₓ) and water vapour in their condensation trails. However, it should be noted that there is significant scientific uncertainty with regard to these estimates, and research is ongoing in this area.


5 Taken from JRC (2008) Backcasting approach for sustainable mobility Luxembourg, EUR 23387/ISSN 1018-5993, Office for Official Publications of the European Communities.
The principal source of transport’s GHG emissions is the combustion of fossil fuels. Currently, petrol (motor spirit), which is mainly used in road transport (e.g. in passenger cars and some light commercial vehicles in some countries), and diesel, which is used by other modes (e.g. heavy duty road vehicles, some railways, inland waterways and maritime vessels) in various forms, are the most common fuels in the transport sector (see Figure 4). Additionally, liquid petroleum gas (LPG) supplies around 2% of the fuels for the European passenger car fuel market (AEGPL, 2009), while the main source of energy for railways in Europe is electricity, neither of which are included in Figure 4. While, alternative fuels are anticipated to play a larger role in providing the transport sector’s energy in the future, currently they only contribute 1.1% of the sector’s liquid fuel use.

1.3 Background to project and its objectives

The context of the EU Transport GHG: Routes to 2050 is the Commission’s long-term objective for tackling climate change, which entails limiting global warming to 2°C and includes the definition of a strategic target for 2050. The Commission’s President Barosso recently underlined the importance of the transport sector in this respect be noting that the next Commission “needs to maintain the momentum towards a low carbon economy, and in particular towards decarbonising our electricity supply and the transport sector”\(^8\). There are various recent policy measures that are aimed at controlling emissions from the transport sector, but these measures are not part of a broad strategy or overarching goal. Hence, the key objective of this project is to provide guidance and evidence on the broader policy framework for controlling GHG emissions from the transport sector. Hence, the project’s objectives are defined as to:

- Begin to consider the long-term transport policy framework in context of need to reduce greenhouse gas (GHG) emissions economy-wide.
- Deal with medium- to longer-term (post 2020; to 2050), i.e. moving beyond recent focus on short-term policy measures.
- Identify what we know about reducing transport’s GHG emissions; and what we do not.
- Identify by when we need to take action and what this action should be.

Given the timescales being considered, the project will take a qualitative and, where possible, a quantitative approach. The project has three Parts, as follows:

- Part I (‘Review of the available information’) has collated the relevant evidence for options to reduce transport’s GHG emissions, which was presented in a series of Papers (1 to 5), and

---

\(^6\) Graph based on figures in DG Energy (2010), page 220


is in the process of developing four policy papers (Papers 6 to 9) that outline the evidence for these instruments to stimulate the application and up take of the options.

- Part II (‘In depth assessment and creation of framework for policy making’) involves bringing the work of Part I together to develop a long-term policy framework for reducing transport’s GHG emissions.
- Part III (‘Ongoing tasks’) covers the stakeholder engagement and the development of additional papers on subjects not covered elsewhere in the project.

As noted under Part III, stakeholder engagement is an important element of the project. The following meetings were held:

- A large stakeholder meeting was held in March 2009 at which the project was introduced to stakeholders.
- A series of stakeholder meetings (or Technical Focus Groups) on the technical and non-technical options for reducing transport’s GHG emissions. These were held in July 2009.
- A series of Technical Focus Groups on the policy instruments that could be used to stimulate the application of the options for reducing transport’s GHG emissions. These were held in September/October 2009.
- Two additional large stakeholder meetings at which the findings of the project were discussed.

As part of the project a number of papers have been produced, all of which can be found on the project’s website, as can all of the presentations from the project’s meetings.

1.4 Background and purpose of the paper

This paper forms part of a suite of papers covering wider issues related to abating greenhouse gas emissions in the transport sector. Together the suite of papers forms Task 9 of the project. A further suite of papers are being developed as part of Task 4, and these papers focus on transport sector abatement options. Whilst this paper covers energy security in the transport sector, there are linkages between this paper and a number of the Task 4 papers. The Task 4 papers cover the following topics:

- Technical options for road transport;
- Technical options for non-road transport;
- Non-technical options for road transport;
- Fiscal and other economic instruments for road transport (incl. ETS);
- Options related to modal shift and intelligent transport systems.

Using evidence from existing studies these Task 4 papers will assess each of these options against a number of key criteria such as cost, carbon savings and barriers to implementation.

1.5 Structure of the paper

The remainder of this paper is structured as follows:

- **Section 2** provides an overview of energy security in relation to the transport sector;
- **Section 3** describes the current and likely future extent of energy security in the transport sector;
- **Section 4** reviews methods for integrating energy security issues into the assessment of options for reducing transport sector greenhouse gas emissions;
- **Section 5** presents a framework for quantifying the energy security impacts of GHG abatement options for the transport sector
- **Section 6** provides a summary of the study’s findings and conclusions.
2 Overview of energy security in relation to the transport sector

2.1 What do we mean by energy security?

There are many different definitions of energy security. All of these definitions include something relating to the sufficient availability and reliability of energy supply, and most definitions stress that the supply should be affordable. For example, in 1985 the International Energy Agency defined energy security simply as:

“An adequate supply of energy at reasonable cost”

More recently, definitions have started to include a sustainability dimension too. In particular there is a focus on climate change and other environmental impacts. This is because energy supplies that come with high greenhouse gas emissions cannot be considered secure in the longer term, given the need to move to a low carbon economy to avoid dangerous climate change impacts. For example the European Commission (EC) Green Paper on security of energy supply stated:

“Energy supply security must be geared to ensuring the proper functioning of the economy, the uninterrupted physical availability at a price which is affordable, while respecting environmental concerns”.

Other definitions include social and political acceptability as added dimensions of energy security, although it could be argued that these aspects are implicit in the sustainability dimension.

For the purposes of this paper we define energy security as being the availability of sufficient, reliable, affordable and sustainable energy supplies.

2.2 What does this mean for transport?

This section provides a brief introduction to the link between energy security and transport. Further details and discussion are provided in subsequent sections.

Energy consumption for transport is dominated today by the demand for oil to produce petrol, diesel, gas oil, marine fuels, and kerosene for road, rail, marine and air transport. There is also a small but growing demand for biofuels, natural gas plays a minor role as a transport fuel, and electricity is used for rail transport. In 2006, oil accounted for over 96% of final energy consumption for transport.

This makes transport, and hence the wider economy of Europe, very dependent on the availability of oil and petroleum products. Therefore, energy security for the transport sector is often equated with oil security.

In future, electricity is likely to take a growing share of energy for road transport in Europe; biofuels are likely to play an important role in the road transport sector, and perhaps in the aviation sector. In Europe, these trends are being driven by climate change concerns more than by energy security concerns, although typically such measures are also positive for energy security.

There are other potential future transport fuel options that could have negative impacts on the environment but are attracting interest due to energy security concerns and energy price rises. These include the production of transport fuels from coal (Coal to Liquids or CTL) and the exploitation of non-conventional sources of oil such as oil shales. Hydrogen could also play a
role as an energy carrier in the transport sector, and significant research and development in this area has been carried out in some countries (including the USA and Japan), primarily as a means of addressing energy security concerns.

2.3 To what extent is the current transport energy supply “not secure”?

This section briefly considers the security of oil supply in the EU against the three dimensions of sufficiency, affordability and sustainability. The extent of energy security is then addressed in more detail in Section 3.

2.3.1 Sufficiency and resource concentration

Europe imports much more oil than it produces and imports are increasing year-on-year. In 2006, EU27 oil imports were 545.6 Mtonnes, 82.6% of total oil consumption. These imports are sourced from a relatively small number of countries, indicating that there is a significant issue with resource concentration; for example, it has been estimated that around 62% of global proven oil reserves are in the Middle East, whilst the chart below shows that 33% of the oil imported into the EU27 in 2006 came from Russia.

So far this import dependency has not led to physical unavailability – sufficient oil is available on the international market, although there have been localised incidents (mainly political in nature) where there have been short term disruptions. In future though there are concerns about availability due to growing demand in non-OECD countries such as China coupled with political instability in many of the oil producing countries. Figure 2.1 shows the sources of imports to the EU in 2007; of the main source countries only Norway can be considered very stable. However, Norway’s oil reserves are decreasing and output is gradually falling, with oil available for export expected to decrease by 25% between 2010 and 2020.

Figure 2.1 Sources of oil imports to the EU27 in 2007 (%)

Current rates of production are sufficient to meet demand but is there capacity to increase production of oil to meet the expected increase in demand over the coming decades? This

---

9 Oil import data from EU Energy and Transport in Figures 2010
depends on how much remaining oil there is in the ground and the capacity of oil companies to increase the rate of extraction. There are concerns over both of these factors. World oil reserves are notoriously difficult to establish and estimates of the global ultimate recoverable reserves range from under 1,000 billion barrels to over 4,000 billion barrels\footnote{Further information on oil reserve estimates is provided in the IPPR report Energy Security in the UK.}. Many believe that oil production will peak in the next decade as discoveries of new oil fields decline and oil from established fields becomes progressively more difficult and expensive to extract. There are also doubts over the ability of the oil industry to invest sufficiently to boost production levels to meet demand. The IEA has estimated that $4.3 trillion of investment would be needed between 2005 and 2030. It is thought likely that these difficulties in investing to boost production capacity are more imminent than shortages due to a depletion of resources. Some commentators have noted that the high oil prices experienced in 2007 and 2008 were due to limitations in production capacity as Saudi Arabia, the world’s largest oil producer was not able to increase production to help stabilise prices, implying that there was limited, or no spare capacity. Shortfalls in production capacity are likely to lead to high levels of price volatility, with corresponding negative economic impacts. Furthermore, high levels of oil price volatility may lead to an uncertain investment climate for alternative renewable energy technologies.

Once the imported oil has reached the EU it has to be refined and then distributed for use.

There are concerns in the EU over future availability of domestic refinery capacity and its potential impact on fuel prices. Compared to past decades, there is now at times a tight balance between refinery capacity and the demand for certain refined products e.g. diesel/gasoil to meet increased demand compared to petrol. In the near term the gasoline surplus is expected to increase with imports of diesel from the CIS region increasing while new refinery capacity in China, India and the Middle East is expected to deflate prices and reduce the incentive to invest in more refineries in the EU (Purvin and Gertz inc., 2008).

Some investment in hydrocracking and residue conversion may take place to redress the supply imbalance. To an extent, the use of biodiesel will reduce the need for refinery supply and gasoil/diesel imports but a growing share of biogasoline blendstocks such as ethanol in the European gasoline pool would further reduce the market for gasoline from refineries.

The balance between domestic refinery outputs and domestic consumption in the EU and a selection of Member States is presented in the table below, showing that diesel was in short supply in Spain and France and just under demand levels at the EU level in 2007. However the picture is fast changing.

Table 2.1 Refinery output in 2007 as a % of inland market consumption

<table>
<thead>
<tr>
<th></th>
<th>All Petroleum Products</th>
<th>Motor Spirit</th>
<th>Kero-Jet Fuels</th>
<th>Gas/diesel oil</th>
<th>Residual fuel oil</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>DE</td>
<td>118%</td>
<td>124%</td>
<td>52%</td>
<td>110%</td>
<td>267%</td>
<td>119%</td>
</tr>
<tr>
<td>ES</td>
<td>91%</td>
<td>138%</td>
<td>116%</td>
<td>67%</td>
<td>225%</td>
<td>78%</td>
</tr>
<tr>
<td>FR</td>
<td>103%</td>
<td>177%</td>
<td>78%</td>
<td>74%</td>
<td>400%</td>
<td>100%</td>
</tr>
<tr>
<td>IT</td>
<td>139%</td>
<td>174%</td>
<td>95%</td>
<td>131%</td>
<td>180%</td>
<td>112%</td>
</tr>
<tr>
<td>UK</td>
<td>112%</td>
<td>121%</td>
<td>56%</td>
<td>97%</td>
<td>534%</td>
<td>140%</td>
</tr>
<tr>
<td>EU-27</td>
<td>119%</td>
<td>141%</td>
<td>81%</td>
<td>98%</td>
<td>289%</td>
<td>115%</td>
</tr>
</tbody>
</table>

Source: Eurostat (2010)
climate change may increase vulnerability to accidental damage in future, for example by increasing storm surges at refineries and drying out the land through which pipelines run.

2.3.2 Affordability

Although imported oil has always been available to Europe, it has come at a price. Countries that belong to the Organisation of Petroleum Exporting Countries (OPEC) produce just under half of the world’s crude oil and so OPEC has a strong influence on oil prices. This concentration of supply within a trading structure such as OPEC is sometimes referred to as “market power”.

As demand for oil has grown in recent years the surplus capacity (oil that is ready for market but not extracted due to lack of demand) in OPEC countries has fallen. Historically, this surplus has buffered oil prices from changes in demand for oil. Without it, oil prices are subject to much greater uncertainty. *Error! Reference source not found.* shows how crude oil prices have fluctuated over the last five years, reaching a peak weekly average price of about $137/bbl in July 2008 before dropping right back below $40/bbl at the end of last year and then increasing again.

![Figure 2.2 World crude oil prices since January 2005 ($ per barrel)](image)

Because OPEC controls so much of the world supply of oil, it can operate as a cartel to limit production and push up prices. Even rumours of this sort of action can trigger a price rise. This all contributes to uncertainty and volatility in the oil markets.

As part of its “World Energy Outlook” publication, the IEA has produced projections for likely future oil prices (IEA, 2008), and these are presented in Figure 2.3. As can be seen from the chart, the IEA anticipates that oil prices are likely to remain high between now and 2030.
2.3.3 Sustainability

Oil is not a sustainable fuel. As discussed in Section 2.3.1, there are limited reserves of oil and global oil production is likely to peak sometime in the next decade. Oil is also unsustainable in the sense that directly burning petroleum products in vehicles produces carbon dioxide emissions and there is no way of capturing and storing these emissions. Finally, emissions from petrol and diesel fuelled vehicles are a major contributor to poor air quality in cities, particularly in developing countries where vehicle emissions standards are less strict.

2.4 What factors contribute to improving energy security?

There are five main ways of improving energy security:
- Making greater use of indigenous supplies
- Increasing diversity of supply
- Establishing long-term supply arrangements
- Increasing strategic reserves
- Reducing demand

Each of these is discussed briefly below in the context of energy for transport in the EU. Section 4 then describes in more detail some of the main transport policy options available to boost energy security in Europe.

2.4.1 Indigenous supplies

Indigenous supplies of oil are limited and declining in Europe. This is reflected in the projected oil production trend for OECD Europe shown in Figure 2.4. There is some scope to recover more oil through technologies such as enhanced oil recovery (EOR) but it is unlikely there will be major new discoveries of oil in Europe in future. Therefore the only way to increase indigenous supply of transport fuels significantly is to move to alternative fuels such as electricity or biofuels.
A consequence of the fact that indigenous EU oil supplies are declining, but overall demand for oil in the EU is still rising is that the EU now needs to import an increasing proportion of the oil need to operate its economies, and that this trend towards more imports will continue in future years. This has wider impacts on the EU economy as a whole, in that unless the supply of indigenous transport fuels can be increased by diversifying into alternative fuels, an increasing proportion of EU capital will flow to countries outside the EU trading bloc.

2.4.2 Diversity of supply

Diversity of supply encompasses diversity of fuels used for transport, diversity of suppliers of those fuels and diversity of supply routes. Alternative fuels such as electricity, natural gas, biofuels, hydrogen and coal-to-liquid (CTL) fuels can reduce reliance on oil supplies, although it is likely that a majority of vehicles will be petrol or diesel fuelled for many years to come. Furthermore, the ability to rapidly increase the supply of alternative energy sources (e.g. natural gas, biofuels) may have the same effect as increasing strategic reserves - i.e. it may be possible to stabilise global oil prices, by reducing the overall demand for crude oil products.

At the individual vehicle level, there is the option of introducing more flexibly fuelled vehicles which, depending on their design, can use combinations of gaseous fuels, biofuels or liquid petroleum based fuels.

As shown in Figure 2.1, the EU already imports oil from a range of different countries. This helps to reduce reliance on a single source but reduced oil production in a single country can still have a significant impact on oil price, and this is multiplied if OPEC countries act together. Diversity of oil supply routes is less of an issue than for natural gas, which is almost exclusively imported through pipelines. Options for increasing the diversity of supply are discussed in more detail in Section 4 of this paper.

2.4.3 Long-term supply arrangements

Long-term supply arrangements are also a favoured option to ensure security of natural gas supply. However, it should be noted that recent disruptions in natural gas supplies across Europe due to a dispute between Russia and Ukraine highlighted the fact that long-term supply
arrangements may not be enough to ensure energy security, and that diversification of suppliers and supply routes are also important.

Long-term supply arrangements are less relevant for oil, which is traded on the international markets and imported to Europe by ship as well as by pipeline.

2.4.4 Strategic reserves

Since 1968, EU Member States have been required to keep a minimum of 90 days’ supply of petroleum as a Strategic Petroleum Reserve (SPR). This SPR must be kept within the EU but not necessarily within the Member State. These reserves are intended to provide a buffer against short term cuts in supply to the country and may also be used in the event of a fault or industrial action at a refinery.

2.4.5 Demand reduction

Simply reducing the demand for transport fuels will improve energy security – the less oil to be imported the lower the vulnerability to supply constraints or increased oil prices. This can be achieved by improving the efficiency by which fuel is used to provide transport, by encouraging modal shift, improving vehicle efficiencies, introducing measures such as driver training or lower speed limits, and optimising freight logistics. It can also be achieved by reducing the demand for energy services in transport through measures such as better urban planning and telecommuting. Finally, the demand for oil can be reduced by introducing alternative fuels such as electricity, biofuels or hydrogen. Methods for reducing the demand for transport fuels are discussed in more detail in Section 4 of this paper.
3 The extent of energy security in the transport sector

3.1 Existing and projected demand for transport fuels

According to baseline projections by the iTREN-2030 project, passenger transport demand in the EU27 will grow by 26.3% (road), 19.4% (rail) and 36.0% (air) between 2005 and 2030, while the National Technical University of Athens predicts an overall increase of 41% over this period, as shown in Figure 3.1. The rate of growth in passenger transport is seen to slow in the second half of this period, as car ownership saturates, but freight transport activity continues to grow steadily.

Figure 3.1: Projected growth in transport activity in Europe

Although the rate of increase in the demand for passenger transport is slowing in Europe, it is growing rapidly in other parts of the world, notably China and India. The vehicle stock in China increased almost seven-fold from 5.5 million vehicles in 1990 to almost 37 million vehicles in 2006. IEA projections suggest this could reach 230 million vehicles by 2030 (see Figure 3.2 below).

---

12 European Energy and Transport, trends to 2030 – update 2007 (NTUA)
13 IEA World Energy Outlook 2008 – China and India Insights
As Figure 3.3 shows, the demand for energy for transport in the EU today is almost exclusively met by petroleum products (oil) for road and air transport, with a small amount of electricity for rail transport. Biofuel consumption is growing but still represented only about 2.6% of final energy consumption in 2007 (European Commission, 2010). This reliance on oil is expected to continue under a reference or business-as-usual scenario, with energy consumption reaching a plateau as improvements in vehicle efficiencies counteract increases in the demand for transport.

The picture is similar globally, with oil continuing to dominate to 2030 and beyond under the IEA’s baseline scenario (see Figure 3.4). Note also that liquid transport fuels produced from coal (CTL) and gas (GTL) are a feature in the baseline scenario in 2050. However, globally the overall demand for energy for transport increases much more sharply between 2005 and 2030 than it does in Europe. This is significant as it is the global demand for oil that drives energy security concerns rather than increases in the demand in Europe.

This global demand is reduced under the ACT and BLUE scenarios, which represent increasing levels of GHG reduction. The Blue scenario implies reducing global GHG emissions by at least 50% from current levels by 2050, which is the minimum recommended by the Intergovernmental Panel on Climate Change (IPCC) to contain global warming to the relatively safe level of 2.0-2.4°C average global temperature rise.
There is also a significant shift to alternative transport fuels under these GHG constraint scenarios. Fossil fuel changes from being the dominant fuel type in the baseline scenario to accounting for less than half of the total fuel used in the BLUE scenario in 2050. Non-fossil sources include ethanol in 2030 and a combination of hydrogen, electricity, biodiesel and bioethanol in 2050. Both hydrogen and electricity are produced from low carbon sources under this scenario: hydrogen predominantly from fossil sources with carbon capture and storage (CCS) and electricity from nuclear energy, coal & gas with CCS and renewables.

3.2 Existing and projected supply of raw materials for transport fuel production

3.2.1 Oil

Figure 3.5 shows the locations where oil is expected to be produced in 2030 and how that picture has changed since 2001. This reflects the depletion of European and Asian oil fields and suggests that the Middle East will strengthen its position as the major supplier of oil to global markets. This is consistent with the location of proven oil reserves, as shown in Figure 3.6, where again the Middle East has the lion’s share. Middle East OPEC countries will also take the largest share in the expected 20% production increase between now and 2030. Production of conventional oil in non-OPEC countries declines (see Figure 3.7).
Figure 3.5: Projected sources of oil production


Figure 3.6: Proven oil reserves in 2007, as share of total

Source: BP, (2009), Statistical Review of World Energy

Figure 3.7: World oil production by region in the reference scenario

As discussed in Section 2.3.1, there are considerable uncertainties over the extent of global oil reserves, with published figures for global ultimate recoverable reserves ranging from 1,000-4,000 billion barrels. This represents at least 40 years of supply at current levels of consumption but, as we have seen in Section 3.1, demand for oil for transport is set to grow in future. There are two schools of thought on the uncertainties. Some commentators believe the lower end of the range on the basis that oil companies may overestimate reserves because of the way OPEC awards quotas. Others believe that reserves are underestimated because each decade brings new oilfield discoveries and new exploration and production technologies. However, it is anticipated that there will be steep decline in production from existing oil fields between now and 2030 (see Figure 3.8).

**Figure 3.8: World oil production by source in the reference scenario**

![Figure 3.8: World oil production by source in the reference scenario](image)


### 3.2.2 Electricity

Electricity can be produced from a wide range of fuels including coal, gas, oil, nuclear energy, biomass and other renewable sources (hydro, wind, wave, solar etc.). Europe’s current and projected future electricity mix is shown in Figure 3.9, which comes from NTUA modelling.
Gas reserves are limited in the same way as oil reserves and supply is also constrained by the ability to transport gas from producer to consumer, although this picture is changing as more gas is shipped in the form of liquefied natural gas (LNG). Over half of the world’s gas reserves are located in just three countries: Russia, Iran and Qatar. The IEA estimates that proven reserves at the end of 2005 were around 180 trillion cubic metres, or around 40 years of supply under the IEA’s reference scenario.\textsuperscript{14}

Coal is more plentiful with proven reserves of 847 billion tonnes, equivalent to 144 years at the current production rate.\textsuperscript{15} Coal reserves are much more evenly distributed than oil and gas fields but China, India, the USA, Russia, India, Australia and South Africa between them account for over 80% of the reserves.

Uranium resources for nuclear power generation are also well distributed and mainly in politically stable regions, with the largest resources in Canada (28%), Australia (23%) and Kazakhstan (10%). A 2006 report by AEA for the UK Sustainable Development Commission concluded that known conventional resources coupled with estimated additional resources should be sufficient for at least 100 years of nuclear generation at predicted build rates. However, it should be noted that globally there is currently no consensus view of the size of uranium resources.

EU renewable energy resources\textsuperscript{16} vary from country-to-country with much of the hydro resource in the mountainous areas of Scandinavia and the Alpine countries, the greatest solar resources in Southern Europe, onshore wind resources in many countries and a concentration of offshore wind, wave and tidal resources in Northern Europe, particularly the UK.

### 3.2.3 Biofuels

Biofuels can be produced from crops such as rape seed, corn and sugar cane (first generation biofuels) or from agricultural or wood residues (second generation biofuels). Currently the land area used globally for biofuels production is only about 0.14 Gha, compared to around 3.4 Gha for pastures and 1.5 Gha for croplands. However biofuels production is set to increase rapidly in...

\textsuperscript{14} IEA data quoted in Energy Security in the UK: an IPPR fact file
\textsuperscript{15} IEA World Energy Outlook 2008
\textsuperscript{16} The term renewable energy resources refers to the potential in a given geographical area, rather than current installed production capacity.
the coming decade in response to policies introduced in Europe, the US and elsewhere. This has triggered concerns about the extent to which biofuels production will compete with food production, particularly in the developing world and the sustainability of biofuel production in terms of biodiversity loss and lifecycle emissions. There are also concerns that the availability of wood for fuel will be affected.

In 2008, the UK Government’s Gallagher Review addressed the issue of the sustainability of biofuels production and looked at the amount of agricultural land that would be required to meet current and proposed biofuels targets. It concluded that biofuels could take up between 56-276 Mha of land globally by 2020, which represents 1-5% of total agricultural land area. This comes at a time when there is growing demand for agricultural land to feed an increasing population, with some 200-500 Mha of additional agricultural land required for food by 2020. The range of values for land required for biofuels reflects a high degree of uncertainty in the types of biofuel, the extent to which co-products can be used crop yields. The lower end of the range assumes second generation biofuels with co-production, while the top end assumes first generation biofuels with modest yields and no co-production. There are also uncertainties over the area of cultivatable land and, in particular, the availability of marginal land which is not currently used for agriculture but could be used for biofuels production. The Gallagher review concluded that biofuels should be produced from marginal land where possible to reduce impacts on food availability and prices.

### 3.3 Are our transport energy supplies likely to become more or less secure?

As previous sections have shown, the global demand for energy is increasing, both for transport and power generation. This is driving up energy prices and raising concerns about the ability of supply to keep up with demand, particularly for oil and gas. Petroleum fuels will continue to dominate in Europe in the short- to medium-term and this brings concerns about the availability and price of oil imports. In the longer term, electricity and biofuels offer the potential to diversify supply but each has its own energy security issues.

#### 3.3.1 Oil

Oil supply within the EU27 has peaked and is set to decline rapidly. This means greater reliance on imports from the Middle East and elsewhere. The growing economies of China and India will be competing for limited oil supply and it is uncertain whether suppliers will be able to step up investments sufficiently to meet demand (potentially leading to higher prices and higher levels of price volatility). There are also incentives for suppliers to restrict or ration supply so that higher prices are maintained. Political tensions in the Middle East and Eastern Europe are adding to concerns that there may not be sufficient supply to meet demand in future decades.

The increased availability of unconventional oil from tar sands and heavy fuel oils may help to increase supply options but it comes at an environmental cost and there are significant investment costs associated with harvesting these types of resources. However, if oil prices remain high in future years, such development may become economically viable, as long as the significant environmental concerns can be overcome. Similarly the production of liquid fuels from coal or gas could help to meet any gap between supply and demand but there will be a large GHG penalty unless such technologies are combined with carbon capture and storage.

Strategic reserves of oil kept by all EU countries should help to mitigate the threat of disruptions to transport fuel supply due to accidents, terrorist attacks or short-term cuts in imports. In the longer term, climate change may lead to damage to pipeline and refining infrastructure.

#### 3.3.2 Electricity

It is likely that the EU will move towards greater use of electric vehicles in future. Introducing electricity into the mix for transport fuels provides diversity in that the electricity can be produced
from a range of sources. This is particularly true for plug-in hybrid vehicles that can use either electricity or petrol/diesel and so can continue to operate during a shortage of one or the other.

Gas reserves are limited and are likely to be exhausted in a similar time-frame to oil reserves but the reserves of coal and uranium (for nuclear power) are much more extensive and better distributed geographically. This means that there should be sufficient raw materials for electricity generation to meet demand in the medium to long term, although there is a potential conflict with GHG reduction measures if coal was to be used for power generation without capturing the resulting carbon dioxide. Similarly there remain public acceptability issues with nuclear power.

The EU Renewable Energy Directive is driving the introduction of more renewable electricity across Europe. Most of this will be provided by intermittent sources such as wind and solar power. This brings challenges in managing the electricity grid, since there is very little capacity for storing electricity and so other (fossil-based) power plants will need to fill the gap at times of high demand when the wind is not blowing and the sun is not shining. These challenges would be heightened if there was a large and rapid uptake of electric or plug-in hybrid vehicles, although such vehicles could also be part of a demand management strategy.

The electricity infrastructure is also inherently more vulnerable to accident or attack than the oil supply infrastructure. This is partly because generation and transmission are centralised and partly because there is no buffering in the system akin to strategic reserves of oil.

### 3.3.3 Biofuels

One of the key benefits associated with biofuels is the diversity of supply available; biofuels can be produced from very many different resource feedstocks, and in future years, as second generation biofuel technologies become commercially available, the range of possible feedstocks is likely to increase. Current feedstocks include palm, soy, oilseed rape, cereal crops, and jatropha. Second generation biofuel technologies will allow the use of crop residues and waste materials to be used to produce biofuels.

However, whilst in theory there are many feedstock options available for producing biofuels, wider sustainability concerns may, in practice, limit the range of available choices, particularly for first generation fuels. In particular, there are significant concerns with regard to land availability, direct land use change and indirect land use change that may place limits on the production of biofuels. As targets for the uptake of biofuels around the world increase in future years, there is likely to be increased competition for land to grow biofuels, and this will need to be weighed against the demand for land to grow food crops. This issue is discussed in more detail in Section 4.5.

Much biofuel production contains embedded fossil fuels, either as a result of the production of fertilisers or used to power the biofuel processing facilities. The proportion varies significantly depending on the fuel and processing facility. The more fossil fuel that is used, the lower the degree of separation from the energy security risks facing the fossil fuel supply.

A side effect of the increased use of biofuels is that the prices of the commodities used to produce the biofuel are themselves becoming strongly linked to the price of oil. At higher oil prices these correlations approach one.
4Existing approaches to quantifying energy security benefits of GHG abatement options

4.1 Introduction

Whilst research has already been carried out to analyse the GHG benefits associated with different emissions abatement options for the transport sector, the effects that such options are likely to have on energy security have not been fully quantified to date. Initial work in this area has been carried out by the International Energy Agency (IEA), Ecofys, the World Resources Institute (WRI) and ECN amongst others, and are reviewed in this section of the report. However, these approaches do not take account of all aspects of energy security and no detailed analysis has been carried out for some of the most important measures applicable in the transport sector.

This section considers how previous studies by the IEA, the WRI and ECN have attempted to assess the impacts of GHG reduction policies on energy security, and vice versa, and how they have presented the results. It also summarises a review of existing indicators for quantifying energy security, carried out for the European Commission in 2009 by the consultancy Ecofys. These are by no means the only studies undertaken in this area but together they provide a good overview of the options and issues.

In Section 5, an alternative approach to quantifying energy security benefits in the transport section is then outlined and demonstrated using semi-quantitative scoring.

4.2 IEA approach to quantifying energy security impacts

In 2007, the IEA published a paper entitled “Energy Security and Climate Policy: Assessing Interactions” (Lefevre, 2007), which reviewed the interactions between energy security and climate change mitigation policies. Importantly, this paper proposed the use of simplified quantitative indicators that can be used as a means by which policy-makers can develop policies that achieve both energy security and climate change objectives in an efficient and effective manner. The research presented in the IEA’s paper identified that energy security policies tended to focus on the root causes of energy security, and that these policies can be categorised into four main types, as follows:

- Energy system disruptions linked to extreme weather events or accidents;
- Short-term balancing of supply and demand in electricity markets;
- Regulatory failures;
- Concentration of fossil resources.

By categorising energy security policies in this manner, the interactions between each category and climate change mitigation policies can be qualitatively assessed. The IEA identified that policies that address the concentration of fossil resources are likely to have the most significant implications for climate change mitigation policies and vice versa. By contrast, policies that address energy system disruptions, and policies that address short-term grid balancing have almost no overlap/interaction with climate change policies. Between these extremes, it was found that regulatory failures may have some secondary interactions with climate change policies. Taking these findings into account, the IEA approach to examining energy security and climate change interactions is based on focussing only on policies that address the concentration of fossil resources.
The IEA approach then identifies indicators that can be used to quantify aspects of fossil resource concentration. Rather than attempting to quantify welfare losses associated with this resource concentration, the approach uses two key indicators to quantify energy insecurity, namely price and the physical availability of energy. In markets where price is allowed to adjust in response to changes in supply and demand, the IEA approach uses an energy security price indicator referred to as $ESI_{\text{price}}$. This price component is based on how exposed the individual country/market is to individual fossil resources. Countries with high exposure to high concentration fossil markets are deemed to have low energy security.

For markets or countries where price is regulated and does not change in response to variations in supply and demand, it is necessary to use a physical unavailability indicator as a metric of energy security. This indicator is referred to as $ESI_{\text{volume}}$, and is mainly useful for gas pipeline trading. $ESI_{\text{volume}}$ represents a country’s proportion of energy demand that is met by gas imports transported by pipeline. As this proportion increases, the less secure the country’s gas supply is.

The approach developed by the IEA was tested by carrying out case study analysis on five different countries, covering the time period to 2020. A range of climate change mitigation scenarios were analysed to examine their impacts on the indicators $ESI_{\text{price}}$ and $ESI_{\text{volume}}$. The IEA found that the use of these indicators enables the impacts of climate change mitigation measures on energy security in individual countries to be analysed in a quantitative manner. Importantly, the approach allows quantitative analysis to be carried out without directly monetising the impacts of energy insecurity.

### 4.3 Ecofys study for the European Commission

In 2009, the European Commission DG Environment commissioned a study from the consultancy Ecofys, supported by Redpoint and ERAS, entitled “Analysis of Impacts of Climate Change Policies on Energy Security”. This study examined the interactions between achieving a sustainable energy system and improving energy security. Additionally, the study was focused on developing a methodology to identify and quantitatively assess the impacts of, and interactions between, climate policies and energy security. As part of this research, a comprehensive review of existing indicators for quantifying energy security was carried out. Drawing from this recent review, it is clear that there are two types of indicator that can be used for quantifying energy security impacts/benefits, as follows:

- Vulnerability-based indicators
- Outcome-based indicators

As set out in the Ecofys paper, vulnerability-based indicators can be used to quantify the “potential risk and/or magnitude of energy security impact should it actually occur”, whilst outcome-based indicators “aim to measure the actual outcome of energy security”, in terms of real-world impacts. Ecofys found that the majority of existing energy security indicators are vulnerability-based indicators; a full list of the indicators identified by Ecofys is presented in the box below.
For this paper, we have not repeated the analysis of different approaches as the Ecofys study provides a comprehensive review. However, it is worth summarising the key findings from the Ecofys study. These were as follows:

- The vast majority of energy security indicators focus on quantifying potential vulnerability to risk and potential magnitude of risk rather than outcomes;
- Outcome-based indicators tend to make use of detailed, situation-specific modelling, and as such are more limited in how widely they can be applied. Vulnerability-based indicators can be more widely used.
- None of the current energy security indicators are able to provide a suitable measure of all the causes of energy security, and attempts to do this reduce the transparency of the indicator.
- For a number of the indicators, the linkage between the indicator and energy security is not clear. Examples include net import dependence, which has been proposed as a proxy indicator for physical unavailability impacts, and the general business environment, which has been proposed as a proxy for investment in energy infrastructure.

The Ecofys study concluded that whilst ideally it would be preferable to develop outcome-based indicators that can be used to assess the actual impacts of energy security on the real world, such an approach would be too complex. With this in mind, Ecofys proceeded to develop a vulnerability-based approach for assessing energy security that draws on previous work carried out by the IEA that led to the development of their energy security indices for price and volume (ESI_{price} and ESI_{volume}).

Ecofys developed a number of indicators to examine what they deemed to be the main root causes of energy insecurity, as summarised in the table overleaf.
Table 4.1: Energy security indicators

<table>
<thead>
<tr>
<th>Root Cause of Energy Insecurity</th>
<th>Indicator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extreme events (covers both extreme weather and other extreme events within same formulae)</td>
<td>Overall Short-Run availability of primary fuel (gas)</td>
</tr>
<tr>
<td></td>
<td>Overall short-Run availability of primary fuel (oil)</td>
</tr>
<tr>
<td></td>
<td>Further De-rated electricity peak capacity margin (adjusted for loss of plant and/or further de-rating for primary fuel shortage)</td>
</tr>
<tr>
<td>Inadequate Market Structure – Insufficient investments in new capacity</td>
<td>Capital Intensity</td>
</tr>
<tr>
<td></td>
<td>Average Load Factor</td>
</tr>
<tr>
<td></td>
<td>Cumulative required new capacity</td>
</tr>
<tr>
<td>Inadequate market structure: Load balancing failure</td>
<td>De-rated electricity peak capacity margin</td>
</tr>
<tr>
<td></td>
<td>Flexibility Margin</td>
</tr>
<tr>
<td>Supply shortfall associated with resource concentration</td>
<td>Resource Concentration Price Indicator (markets characterized by an effective price mechanism)</td>
</tr>
<tr>
<td></td>
<td>Resource Concentration Physical Availability Indicator (markets with no or limited price mechanism)</td>
</tr>
<tr>
<td></td>
<td>Alternative Stage IV indicator - Adjusted Share of Primary Fuel in FEC (Applies to any non-electricity related Stage IV)</td>
</tr>
</tbody>
</table>

Consideration was also given to the flexibility of the rest of the supply-chain to cope with disruptions (price or physical unavailability) and the nature of the demand for the particular energy source being considered (the magnitude of demand and the flexibility for demand to shift in time or to alternative energy carriers). In general, most indicators were examined for each primary fuel (e.g. gas, oil and coal) separately and then aggregated on the basis of the share of each fuel in total primary consumption – to form a single indicator (this takes place at Stage IV). Ecofys did not aggregate across multiple indicators to create a single overarching ‘score’ for energy security because of risks in treating all indicators with equal weight and aggregating indicators with different metrics.

Ecofys applied their indicator approach under a baseline scenario and two alternative scenarios (climate package and climate package plus CCS), as well as several country and policy specific case studies (focusing on renewables, CHP and the Large Combustion Plant Directive). While Ecofys did not apply the approach to specific transport policy options, some of the indicators could be useful in assessing the energy security impact of different transport policy options.
4.4 World Resources Institute approach

The World Resources Institute (WRI) has developed a semi-quantitative approach for comparing the energy security and climate change impacts of different energy options. The approach uses a mixture of quantitative analysis and expert judgment to arrive at conclusions for the likely impacts of different policy options. The WRI approach uses an easy-to-understand method for graphically representing both the climate and energy security impacts of different options in a single chart, allowing different options to be easily compared. The chart below presents the climate and energy security impacts of selected energy options in the USA for the year 2025.

Figure 4.1: WRI approach for comparing the energy security and climate change impacts of energy options

In the above chart, the size of each bubble provides an indication of the amount of energy that the specific option could deliver (or offset) in 2025, over and above the business as usual scenario. Each bubble represents the amount of primary coal or oil that would be offset by the specific measure. Coal was used to represent power sector options and oil was used for transport sector options. The estimates for the size of each bubble were made by combining quantitative data taken from existing forecasts with a qualitative assessment carried out by WRI researchers.

Within the chart, climate change impacts are presented along the y-axis, with beneficial options appearing above the x-axis and options with negative climate impacts appearing below the x-axis line. The position of each bubble along the y-axis takes into account the impact that the option has on life-cycle greenhouse gas emissions, and hence it is possible to use quantitative data to assess the climate impacts of each option in a consistent manner.

Energy security impacts are presented along the x-axis, with options that improve energy security appearing to the right of the y-axis line and options that reduce energy security appearing to the left of the y-axis. WRI has not been able to take a quantitative approach to assessing the impacts of each option on energy security, and hence the placement of each bubble is based on qualitative assessment. In order to carry out this qualitative assessment, an expanded definition of energy security was used. WRI categorised the sub-elements that contribute to energy security as:

- Sufficiency
- Reliability
- Affordability
- Social acceptance; and
- Geopolitical factors

For each of these elements, WRI carried out qualitative analysis to determine whether the impacts of each individual energy option would be positive or negative, and provided a rationale to explain their classification. The outputs from this work were then used to place each bubble along the x-axis. WRI makes clear that their approach to assessing energy security provide one set of answers, but that other analysis could come up with an alternative view for each option.

The benefits of the WRI approach include the ability to compare, visually, the trade-offs between the energy security impacts and the magnitude of potential climate change impacts of individual energy policy options.

### 4.5 ECN approach

The Environmental Research Centre of the Netherlands (ECN) has addressed the linkage between energy security and climate change through what it calls the ESCAPE approach - Energy Security and Climate Policy Evaluation. Their proposition is that linking climate change policy with security of energy supply may improve climate policy at both national and international level.

ECN uses a semi-qualitative scoring approach to assess the security of energy supply (SoS) and GHG impacts of a given policy objective. Table 4.2 shows a subset of their resulting assessment of policy options, focusing on those that relate most to transport. The full table includes gas, coal, nuclear and renewable energy policy options and is available from the RIVM web site.

---

[18](http://www.rivm.nl/bibliotheek/rapporten/500036001.pdf)
The security of supply score appears to be somewhat subjective and is based on four criteria: diversification of energy sources in energy supply; diversification of imports; long-term political stability in regions of fuel origin; the resource base in regions of origin. This gives scores ranging from -5 (highly negative impact) to +5 (highly positive impact). The GHG scores are based on the CO$_2$ emission factors of the respective fuels only, although other environmental impacts are being considered separately in ECN's work. For example replacing coal with oil attracts a score of +1 while replacing coal with biomass is given +4.

ECN has identified a number of options that reduce import dependency as well as GHG emissions, including renewable energy, biofuels and nuclear power. It has also used the ESCAPE approach to propose ways in which energy security aspects could be integrated into sectoral approaches to a post-Kyoto climate agreement. Further information is available from the RIVM report\textsuperscript{18} and a related ECN paper\textsuperscript{19}.

### 4.6 Summary

The foregoing analysis has reviewed a selection of approaches that could be used for analysing the energy security impacts of greenhouse gas emissions abatement options in the transport sector. It is stressed that this is not an exhaustive review, and that there are may be other assessment methods that have been developed by other researchers. Both the WRI and ECN approaches use qualitative frameworks for assessing the impacts of options on energy security. Whilst these frameworks have the advantage of allowing policy options to be analysed both for the impact on energy security and greenhouse gas emissions, to a large extent these approaches are subjective in nature. This means that it is possible that different researchers may come up with alternative findings when assessing the same abatement options using these frameworks. The IEA and Ecofys assessment frameworks adopt a more quantitative approach to assessing energy security impacts, and hence this could be a more robust method for analysing this issue.

---

\textsuperscript{18} ESCAPE: Energy Security & Climate Policy Evaluation, ECM-C-05-032

\textsuperscript{19} ESCAPE: Energy Security & Climate Policy Evaluation, ECM-C-05-032
5 Proposed approach for quantifying the energy security impacts of GHG abatement options for the transport sector

5.1 Introduction

As discussed in the previous section of this report, existing approaches for the quantification of energy security impacts of policies and measures are not ideally suited to estimating the energy security impacts of transport policies. In particular, a full review of the energy security impact of biofuels and renewable electricity sources has not previously been carried out; this is important, as both of these energy sources are likely to become very important for the transport sector in the coming years. Furthermore, existing approaches do not take into account transport-specific factors such as the current and/or future ability of vehicles to switch to alternative fuels.

In this section of the report, an alternative approach to quantifying the energy security impacts of GHG abatement options for the transport sector is outlined and demonstrated using selected examples. We stress that given the limited nature of this study, the approach outlined in this report is presented as an initial idea that has not yet been fully fleshed out. Further work would be required to develop this methodology comprehensively and in particular, further research is required to identify quantitative values for a number of the key parameters. However the paper sets out a relatively simple initial framework designed specifically with transport measures in mind, and that has been developed on the basis that it can be adapted and modified in the future.

5.2 The proposed approach

5.2.1 Introduction

In the transport sector, there are essentially two broad options to lower GHG emissions that affect energy security: decreasing the overall amount of energy used and fuel switching.

Ecofys (2009) identify four root causes of energy insecurity:

- Extreme events (covers both extreme weather and other extreme)
- Inadequate Market Structure – Insufficient investments in new capacity
- Inadequate market structure – Load balancing failure
- Supply shortfall associated with resource concentration

In assessing the energy security impacts of transport measures, all of these factors are important, and the approach that has been developed includes an assessment of these key parameters. Resource concentration is a particularly important issue for the transport sector, particularly with regard to supplies of crude oil. As discussed in Section 3, EU natural gas supply is more concentrated and more subject to control by suppliers than the EU oil supply. However, the dominance of OPEC over the oil market may increase in the coming decades.

The following parameters have been defined to determine the energy security impacts of GHG abatement options for the transport sector:

(a) linkage between price of new energy source and oil price
(b) proportion of vehicle fleet able to use new energy source
(c) cost of new energy source compared to oil
(d) surplus of supply capacity over demand
(e) susceptibility of new energy source to disruptions (extreme events and inadequate market structures)
(f) resource concentration for the supply of the new energy source

A more detailed description of each of these parameters is presented in Section 5.3.

In order to be able to develop a full quantitative approach for assessing the energy security impacts of possible GHG reduction policies for the transport sector, it would be necessary to have access to quantitative data for all of the above parameters for each potential new energy source. Only in this way could all the energy security impacts/benefits be fully evaluated. It was not possible within the scope of this project to carry detailed analysis to identify quantitative data for each of the key assessment parameters. Indeed, for many of the parameters, it may not be possible to readily identify quantitative datasets, and at this point in time, data are not available for all alternative energy sources to cover the full 2010-2050 timeframe.

Nonetheless, an initial framework has been developed using the above-listed parameters as the basis for assessing energy security impacts and benefits. The framework is applied using a semi-quantitative approach (multi-criteria analysis) to quantify the energy security benefits of transport options. Using this approach, it is possible to calculate numerical energy security ratings for each abatement option.

### 5.2.2 Multi-criteria analysis

Traditionally, emissions abatement options for the transport sector might be assessed using Cost-Benefit Analysis techniques, where impacts (such as emissions reductions or the number of lives saved due to the implementation of the option) can be quantified in terms of their monetary values. However, the limitation with this approach is that other wider impacts are not taken into account in the analysis, and whilst it is possible to provide monetary values for some other impacts in order to do this, detailed information on the effects that options have on each of these parameters is required and some parameters such as energy security impacts are very difficult to quantify in monetary terms.

One method of including the wider impacts in the assessment and prioritisation of options is to use Multi Criteria Analysis (MCA). The technique is particularly suited to options where there are relatively large numbers of performance criteria against which the options are being judged, and where there is a lack of detailed, quantitative data. A key feature of MCA techniques is the use of performance matrices where each row describes an option, and each column describes the performance of the option against a particular criterion. In this study, the MCA performance matrix used includes mostly qualitative assessments on the performance of individual options against the energy security parameters defined above. Further work would enable actual quantitative estimates to be substituted in many cases.

The assessment of various alternative transport options produced a series of scores for each option against the energy security parameters. The results of these assessments were converted to numerical values and used as the input data for the Multi-Criteria Analysis.

The next step in the MCA process was to normalise the numerical scores against each criterion in the performance matrix to a common scale. Typically, all the scores are normalised so that they appear on a scale between 0 and 100 (“0” indicates the least preferred option and “100” the most preferred option). The results of the assessment are presented in Section 5.3.

No weighting of the results has been carried out at this stage but weighting should be considered in the further development of the approach to reflect the relative importance of each parameter.
Moreover, further work is required beyond this project to develop a more complete approach to quantification, building on the IEA and Ecofys work reviewed in Section 4. In particular more work is required on the following aspects:

- analysis of the impact of various different biofuel resource feedstocks
- more detailed analysis of electricity sources including intermittent (renewable) and non-intermittent (nuclear, coal/coal CCS, biomass, pumped hydro) sources and links to resource concentration issues

These aspects will be particularly important as both biofuels and electricity are likely to become increasingly important in the transport sector in future years.

Whilst the proposed approach is, to a certain extent, subjective in that expert judgment needs to be applied to produce semi-quantitative scores for many of the assessment criteria, the benefit of this approach is that as and when hard, quantitative data becomes available, these datasets can be used in place of the semi-quantitative scores, thereby enabling more robust analysis to be carried out. In this way, we anticipate that the methodology should evolve and adapt over time, drawing upon the latest research findings.

5.3 Demonstration of the approach for light duty road vehicles

Indicative results have been produced by applying the approach outlined above and using semi-quantitative data and qualitative scoring based on expert judgement.

The following parameters and data sources form the basis of the assessment.

<table>
<thead>
<tr>
<th>Description</th>
<th>Source used for semi-quantitative scoring</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Linkage to oil price</strong></td>
<td></td>
</tr>
<tr>
<td>Oil price is forecast to increase and to become increasing volatile in the future. Where the price of an alternative fuel is closely linked to that of oil, we consider there to be a negative impact on energy security.</td>
<td>European Commission JRC (2005), Wells-to-Wheels Study “oil cost factors” (OCF). OCF are expressed as a fraction of the change in crude price e.g. with an OCF of 1 the price would track that of crude oil; with an OCF of 0.5 a doubling of crude price would result in a 50% increase.</td>
</tr>
<tr>
<td><strong>Proportion of current vehicle fleet able to use the alternative fuel</strong></td>
<td></td>
</tr>
</tbody>
</table>
| The degree to which energy security will be affected by any given transport measure is dependent on the level of impact the measure could have in practice - one limiting factor is the capacity of existing vehicles to accommodate the measure. Closer to 2050 this becomes an irrelevant factor given the lifetime of vehicles in the current fleet. Some vehicles may also be replaced before the end of their average lifetime as a result of the measure. It may therefore be appropriate to give this factor a low weighting in future assessments. | Scoring is applied using expert judgement and converted into numerical values using the following scores:  
  - High 3;  
  - Medium 2;  
  - Low 1  
with 3 representing a high positive effect on energy security. |

| Fuel Cost (€/MJ)                                                           |                                                                                                          |

### Description

| High fuel costs are deemed to have a negative impact on energy security. | The scoring is based on expert judgement. Further work is required to look in detail at actual costs (€/MJ) and variation in specific markets. The cost of the vehicle is not considered here. Full life cycle costs per km could be calculated to reflect on the impacts on affordability of the measure. |

### Susceptibility to disruptions (extreme events and inadequate market structures)

| The susceptibility of the alternative fuel source or measure to supply disruption as a result of an extreme event (e.g. storm, civil unrest, political tension or terrorist attack) or market failures (e.g. inadequate investment in sufficient infrastructure or system overloading). | Scoring is applied using expert judgement and converted into numerical values using the following scores:
- High 1;
- Medium 2;
- Low 3
with 3 representing a positive effect on energy security. |

### Surplus supply capacity

| Production minus global demand. | Scoring is applied using expert judgement and converted into numerical values using the following scores:
- High 3;
- Medium 2;
- Low 1
with 3 representing a high positive effect on energy security. |

### Resource concentration of energy source

| This factor reflects dependence on a relatively few suppliers or supply routes. | Scoring is applied using expert judgement and converted into numerical values using the following scores:
- High 3;
- Medium 2;
- Low 1
with 3 representing a high positive effect on energy security. |

Each alternative energy source is assessed against each energy security parameter to determine the impact on energy security. The alternative energy sources used here are for demonstration purposes. A full assessment would take account of different biofuel feedstocks and the various fuel sources used for electricity generation for example. The sources of information used to prepare the initial scoring are listed in the table above. It should be stressed that the assessment presented below is based on the current situation with respect to fuel costs, vehicle capabilities, and the current methods used to produce the fuels included in this analysis. For example, it has been assumed that hydrogen is produced from natural gas (steam methane reforming process), and consequently many of the scores assigned to this energy carrier. If the assessment were to be carried out for future years, then it is anticipated that the results and ranking of options would be very different (e.g. hydrogen could be produced from alternative energy sources, the ability of the vehicle fleet to use alternative fuels such as electricity could be much greater, etc). With this in mind, the analysis results presented below should only be viewed as illustrative of the situation now, and not representative of future years.
### Figure 5.1 Results of the multi-criteria analysis: Step 1

<table>
<thead>
<tr>
<th>Abatement option</th>
<th>Linkage to oil price (OCF)</th>
<th>Proportion of current vehicle fleet able to use the fuel</th>
<th>Fuel Cost (€/MJ)</th>
<th>Susceptibility to disruptions (extreme events and inadequate market structures)</th>
<th>Surplus supply capacity</th>
<th>Resource concentration of energy source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline/diesel</td>
<td>1.3</td>
<td>HIGH</td>
<td>MED</td>
<td>MED</td>
<td>MED</td>
<td>MED</td>
</tr>
<tr>
<td>LPG</td>
<td>1.2</td>
<td>LOW</td>
<td>MED</td>
<td>MED</td>
<td>MED</td>
<td>MED</td>
</tr>
<tr>
<td>NG</td>
<td>0.8</td>
<td>LOW</td>
<td>MED</td>
<td>HIGH</td>
<td>MED</td>
<td>MED</td>
</tr>
<tr>
<td>Biofuel blends and fungible types</td>
<td>0.5</td>
<td>HIGH</td>
<td>HIGH</td>
<td>MED</td>
<td>LOW</td>
<td>LOW</td>
</tr>
<tr>
<td>Pure non-fungible biofuel&lt;sup&gt;1&lt;/sup&gt;</td>
<td>0.5</td>
<td>LOW</td>
<td>HIGH</td>
<td>MED</td>
<td>LOW</td>
<td>LOW</td>
</tr>
<tr>
<td>Hydrogen&lt;sup&gt;2&lt;/sup&gt;</td>
<td>0.8</td>
<td>LOW</td>
<td>MED</td>
<td>HIGH</td>
<td>MED</td>
<td>HIGH</td>
</tr>
<tr>
<td>Electricity</td>
<td>0.5</td>
<td>LOW</td>
<td>LOW</td>
<td>HIGH</td>
<td>HIGH</td>
<td>LOW</td>
</tr>
<tr>
<td>Energy demand reduction</td>
<td>1.3</td>
<td>HIGH</td>
<td>MED</td>
<td>LOW</td>
<td>HIGH</td>
<td>LOW</td>
</tr>
</tbody>
</table>

<sup>1</sup>Including e.g. fatty acid methyl esters (FAME) and ethanol

<sup>2</sup>Production from the steam methane reforming using natural gas is assumed

The qualitative assessments above are then converted into numerical values, paying close attention to reflecting the nature of the impact on energy security, whether it be a negative or positive one. The following table presents the results of this process.

### Figure 5.2 Results of the multi-criteria analysis: Step 2

<table>
<thead>
<tr>
<th>Abatement option</th>
<th>Linkage to oil price (OCF)</th>
<th>Proportion of current vehicle fleet able to use the fuel</th>
<th>Fuel Cost (€/MJ)</th>
<th>Susceptibility to disruptions (extreme events and inadequate market structures)</th>
<th>Surplus supply capacity</th>
<th>Resource concentration of energy source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline/diesel</td>
<td>1.3</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>
Finally, the numerical scores are normalised against each parameter in the performance matrix to a common scale. All of the scores are normalised so that they appear on a scale between 0 and 100 ("0" indicates the least preferred option and "100" the most preferred option). The results of the assessment are shown below.

**Figure 5.3 Results of the multi-criteria analysis: Step 3**

<table>
<thead>
<tr>
<th>Abatement option</th>
<th>Linkage to oil price (OCF)</th>
<th>Proportion of current vehicle fleet able to use the fuel</th>
<th>Fuel Cost (€/MJ)</th>
<th>Susceptibility to disruptions (extreme events and inadequate market structures)</th>
<th>Surplus supply capacity</th>
<th>Resource concentration of energy source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline/diesel</td>
<td>0</td>
<td>100</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>LPG</td>
<td>13</td>
<td>0</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>NG</td>
<td>63</td>
<td>0</td>
<td>50</td>
<td>0</td>
<td>50</td>
<td>0</td>
</tr>
<tr>
<td>Biofuel blends and fungible types</td>
<td>100</td>
<td>100</td>
<td>0</td>
<td>50</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>Pure non-fungible biofuel¹</td>
<td>100</td>
<td>0</td>
<td>0</td>
<td>50</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>Hydrogen fuel cell²</td>
<td>63</td>
<td>0</td>
<td>50</td>
<td>0</td>
<td>50</td>
<td>0</td>
</tr>
<tr>
<td>Electricity</td>
<td>100</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>
Abatement option & Linkage to oil price (OCF) & Proportion of current vehicle fleet able to use the fuel & Fuel Cost (€/MJ) & Susceptibility to disruptions (extreme events and inadequate market structures) & Surplus supply capacity & Resource concentration of energy source \\
--- & --- & --- & --- & --- & --- & --- \\
Energy demand reduction & 0 & 100 & 50 & 100 & 100 & 100 \\

The results derived when totalled and ranked are presented in Table 5.2. The highest scores indicate the most preferred options from an energy security perspective.

Table 5.2 Results of the multi-criteria analysis: Step 4

<table>
<thead>
<tr>
<th>Transport Policy Option</th>
<th>Total MCA score (maximum 600)</th>
<th>MCA score as a percentage</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy demand reduction</td>
<td>450</td>
<td>75%</td>
<td>1</td>
</tr>
<tr>
<td>Electricity</td>
<td>400</td>
<td>67%</td>
<td>2</td>
</tr>
<tr>
<td>Biofuel blends and fungible types</td>
<td>350</td>
<td>58%</td>
<td>3</td>
</tr>
<tr>
<td>Gasoline/diesel</td>
<td>300</td>
<td>50%</td>
<td>4</td>
</tr>
<tr>
<td>Pure non-fungible biofuel¹</td>
<td>250</td>
<td>42%</td>
<td>5</td>
</tr>
<tr>
<td>LPG</td>
<td>213</td>
<td>35%</td>
<td>6</td>
</tr>
<tr>
<td>Natural gas</td>
<td>163</td>
<td>27%</td>
<td>7</td>
</tr>
<tr>
<td>Hydrogen (produced from natural gas)</td>
<td>163</td>
<td>27%</td>
<td>7</td>
</tr>
</tbody>
</table>

5.4 **Interpretation**

The analysis clearly shows that under current conditions, the optimal energy security benefit is obtained by approaches that reduce the overall demand for energy. The figures above also identify electricity and biofuel blends to be the next best options for energy security in the transport sector due to their low resource concentration levels and, for electricity, a low correlation with crude oil prices. The proportion of vehicles able to use electricity is however very low but high for blended biofuels. Natural gas and hydrogen produced using natural gas score low in the assessment due to high resource concentrations and susceptibility to extreme events, as well as the small proportion of vehicles that can use them. As highlighted earlier, the results and rank ordering would look very different if the analysis were to be carried out for future years.

5.5 **Further development of the approach**

The assessment framework presented in Sections 5.2 and 5.3 provides a means of quantifying the energy security impacts of different transport sector emissions abatement options, and a means for ranking these options on the basis of their energy security performance. Whilst it is recognised that the proposed approach is, to a certain extent, subjective in that expert judgment needs to be applied to produce semi-quantitative scores for many of the assessment criteria, the benefit of this approach is that it provides a framework that can be adapted and improved in the future. In particular, as and when hard, quantitative data become available, these datasets can be used in place of the semi-quantitative scores, thereby enabling more robust analysis to be carried out. It is likely that existing indicators reviewed in this paper (e.g. $ESI_{price}$ and $ESI_{volume}$), or
the Energy Security Market Concentration (ESMC) indicator, which is based on the Herfindahl-Hirschman Index\textsuperscript{20} could also be integrated into the framework. In particular, the latter indicator could be used as a more objective measure of resource concentration. The assessment criteria that could already be populated with actual numerical data include the following parameters:

- Proportion of the vehicle fleet able to use the fuel in question (could be obtained from national-level vehicle licensing statistics)
- Fuel cost data (from fuel statistical datasets)
- Resource concentration (e.g. ESMC indicator)

The aim, over time, should be to replace all of the subjective, semi-quantitative scores, with more objective, quantifiable indicators that are based on identifiable evidence. In this way, we anticipate that the methodology should evolve and adapt over time, drawing upon existing datasets and new research findings.

There are a number of other limitations in the approach which should be addressed in future work. For example, a more comprehensive assessment would take account of such complexities as the unique characteristics of individual biofuel feed-stocks and would explore resource concentration and other issues associated with renewable energy sources. These aspects will be particularly important as both biofuels and electricity are likely to become increasingly important in the transport sector in future years. A more detailed consideration of the transport demand profile may also be incorporated to take account of flexibilities and inflexibilities e.g. road freight transport. There is also a need to examine the energy security impacts of petrol and diesel separately; there is relatively limited excess supply capacity to produce additional diesel fuel in Europe, given overall demand levels for this fuel, whilst there is significant capacity to supply additional petrol to the market. These factors need to be taken into account along with the fact that petrol is essentially only used to power passenger cars, whilst diesel is used for cars, vans, heavy duty trucks, and buses/coaches. A more detailed analysis of energy security would undoubtedly highlight key variations in energy security for these two fossil fuels.

In addition to developing robust, quantitative datasets for each of the assessment criteria, it may also be useful to be able to weight each of the assessment criteria to reflect their respective levels of importance. Previous use of the MCA technique for policy assessment frameworks has highlighted the importance of selecting appropriate weighting factors as these values can influence the results significantly. The development of suitable weighting factors would require discussions with Commission officials and possibly further consultation with industry and NGO stakeholders, in order to ensure that appropriate factors for each of the criteria are developed.

\textsuperscript{20} The Herfindahl-Hirschman Index is equal to the sum of the square of the individual market shares of all the participants in a particular market.
6 Summary and conclusions

This paper has set out the key issues with respect to energy security and the transport sector; in particular it has provided a definition for energy security, it has described what the issue of energy security means for the transport sector, and it has discussed the current and potential future extent to which the transport sector's energy supplies are secure. Furthermore, it has reviewed the means available for increasing energy security in the transport sector.

The paper has reviewed four existing methodologies for integrating energy security issues into the impact assessment of climate change options. The paper presents an alternative framework, developed under this project, to quantify the energy security impacts of GHG policy options in the transport sector. The framework has been demonstrated initially using expert judgement and semi-quantitative data.

The key findings from this study are as follows:

- Energy security has been defined as being the availability of sufficient, reliable, affordable and sustainable energy supplies;

- With respect to the transport sector, energy consumption is currently dominated by crude oil, which is used to produce a variety of transport fuels including petrol, diesel, gas oil, marine fuels and aviation kerosene. With this in mind, energy security in the transport sector is often currently equated with "oil security";

- In order to define how secure the current transport energy supply is, it is necessary to examine the sufficiency, affordability, and sustainability of these supplies. With respect to sufficiency, Europe imports more oil that it produces and imports are growing year-on-year. Whilst this has not yet led to physical unavailability of transport fuels, there have been localised incidents that have led to short-term supply disruptions. Whilst current rates of production are sufficient to meet demand there are concerns that there may not be enough capacity to increase the production of oil to meet the expected increase in demand over the coming decades;

- In general terms, energy security can be improved by making greater use of indigenous fuel supplies, by increasing the diversity of supplies, by establishing long-term supply arrangements, by increasing strategic reserves, and by reducing demand. In the context of the transport sector, it is unlikely that the EU will be able to make greater use of indigenous oil supplies in future years as these supplies are already on a declining trend, and Member States are becoming more reliant on obtaining oil from outside the EU. There is significant scope to increase the diversity of energy supplies used in the transport sector, and some of these options are already being investigated and deployed. Long-term supply arrangements are less relevant in the transport sector than in other sectors, as oil is traded on international markets. However, should there be a shift to alternative fuels, then such arrangements may become more important. With respect to strategic reserves, EU Member States are already obliged to keep a minimum of 90 days' supply of petroleum. Demand reduction measures could play an important role in improving the transport sector's energy security.

- Energy security issues are not currently well integrated within the analysis techniques used to assess greenhouse gas emissions abatement options for the transport sector. A number of previous studies have developed methods of assessing energy security issues in the context of climate change options, and a selection of these approaches have been reviewed. In particular, approaches developed by the International Energy Agency, the World Resources Institute, the Environmental Research Centre of the Netherlands (ECN) and Ecofys were examined. Each of these approaches attempts to analyse energy security issues associated with specific energy options, taking into account specific sub-
elements that contribute to energy insecurity. The approaches proposed by WRI and ECN use qualitative frameworks for assessing energy security impacts, and to a large extent these methods are subjective. In theory, the use of these assessment methods by different researchers could provide alternative views on the energy security impacts of specific options. The IEA and Ecofys approaches use a quantitative framework for assessing the impacts of options on energy security, and hence could be a more robust method for analysing this issue.

- The paper presents an alternative framework, developed under this project, to quantify the energy security impacts of GHG policy options in the transport sector, namely fuel switching (to LPG, natural gas, biofuels, hydrogen or electricity) and demand reduction. The framework uses multi-criteria analysis to combine assessments of each option against six energy security criteria. The framework has been demonstrated initially using expert judgement and semi-quantitative data. Further analysis is required to generate the data required for a more comprehensive quantitative assessment. It is likely that the indicators developed by other researchers, and reviewed in this paper, could be integrated into the framework. A more comprehensive assessment would also take account of such complexities as the unique characteristics of individual biofuel feedstocks and would explore resource concentration and other issues associated with renewable energy sources.
7 References

Agricultural Land Availability and Demand in 2020, CE Delft

BP, (2009), Statistical Review of World Energy


European Commission Joint Research Council, (2005), Well-To-Wheels analysis of future automotive fuels and powertrains in the European context


IEA World Energy Outlook, 2008

IEA, (2008), Energy Technology Perspectives: Scenarios & Strategies to 2050


